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Technical Report
DRDC Toronto TR 2012-084
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Abstract

This study was conducted in response to a Support to Operations/Support to Development Engineering and Evaluation (STO/DEE) request from ADM (Mat) for information relating to Canadian Forces divers' risk of developing noise-induced hearing loss during simulated dives. During a simulated dive, high pressure air is transferred into the dive chamber of a hyperbaric facility. The mechanism is audible and sufficiently high in level in adjacent areas to warrant the use of hearing protection. There were two parts to the experiment, the assessment of hearing protector attenuation and the measurement of sound levels. In Part I, hearing thresholds were measured at frequencies from 250-8000 Hz in twenty normal-hearing males and females (1) with the head uncovered and ears unoccluded, (2) while wearing a wetsuit hood, and (3) while fitted with three hearing protection earmuffs, unvented and vented. Venting, the practice of drilling a small hole in earcups, is meant to prevent eardrum barotrauma. Attenuation was derived by subtracting the unoccluded from the protected thresholds. In Part II, sound level measurements were made at twenty-two positions within the Diving Research and Diving Training Facilities of Defence Research and Development Canada – Toronto. Earmuff venting resulted in a decrease in attenuation of as much as 17 dB at 250 Hz and 500 Hz. Although it was determined that some of the protected sound levels might be unsafe, the exposure duration was sufficiently short to minimize the possibility of hearing damage.

Résumé

La présente étude a été réalisée à la suite d'une demande de soutien aux opérations/au développement, à l'ingénierie et aux évaluations (STO/DEE) formulée par le SMA (Mat) relativement à la collecte de données sur le risque de perte auditive due au bruit chez les plongeurs des Forces canadiennes participant à des exercices de plongée expérimentale. Au cours d'une plongée expérimentale, de l'air haute pression est introduit dans la chambre de plongée d'une installation hyperbare par un procédé audible d'un niveau sonore justifiant le recours à une protection auditive dans les zones adjacentes. Divisée en deux volets, l'étude visait à évaluer le niveau d'atténuation sonore associé à certains protecteurs auditifs et à mesurer les niveaux sonores observés. Au cours du volet 1, les seuils d'audition ont été mesurés à des fréquences de 250-8 000 Hz chez 20 hommes et femmes normo-entendants, selon les paramètres suivants : 1) tête découverte et oreilles non occluses; 2) port d'une cagoule nautique isothermique; 3) port de trois modèles de serre-tête antibruit dotés ou non d'orifices de ventilation. Le perçage d'un petit orifice de ventilation dans les cache-oreilles vise à prévenir les barotraumatismes de l'oreille. L'atténuation sonore a été obtenue en soustrayant les seuils auditifs mesurés sans occlusion des seuils avec protection. Dans le cadre du volet 2, le niveau sonore ambiant a été mesuré à vingt-deux endroits dans les installations de recherche et d'entraînement en plongée de Recherche et développement pour la défense Canada – Toronto. Les orifices de ventilation ont entraîné une réduction du niveau d'atténuation sonore des protecteurs auditifs pouvant atteindre 17 dB à 250 Hz et à 500 Hz. Bien que certains niveaux sonores associés au port d'une protection auditive puissent poser un danger, la durée d'exposition était assez courte pour réduire au minimum le risque d'atteinte auditive.

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Executive summary

The risk of noise-induced hearing loss during simulated dives in Canadian Forces hyperbaric facilities

Sharon M. Abel; Ann Nakashima; Douglas Saunders; Gary Bures; DRDC Toronto TR 2012-084; Defence R&D Canada – Toronto. October2012.

Introduction: This study was conducted in response to a Support to Operations/Support to Development Engineering and Evaluation (STO/DEE) request from ADM (Mat) for information relating to Canadian Forces divers' risk of developing noise-induced hearing loss during simulated dives in hyperbaric facilities. At the commencement of these exercises pressurized air is transferred into the dive chamber of the facility. Since the mechanism is audible and sufficiently high in level in adjacent areas to pose a risk for hearing, the wearing of hearing protection devices is mandatory. The standby diver normally wears a neoprene wetsuit hood. A concern regarding the use of hearing protection is the possibility of barotrauma, a rupture of the eardrum that results from a failure to equalize the pressure between the outer ear and middle ears when the atmospheric pressure rises or falls. Barotrauma may be avoided by drilling a small hole in the earcup (venting) to allow the entry of the surrounding air in the external ear canal. Venting could, however, reduce the sound attenuation that the device could provide.

Methods: The experiment was carried out at Defence Research and Development Canada – Toronto (DRDC Toronto). There were two parts. Part I involved measurement of the sound attenuation that could be achieved with hearing protection devices currently used by navy divers These were the Peltor H10A, Howard Leight Viking, and the Moldex M2 earmuffs, unvented and vented, and a neoprene wetsuit hood. Ten males and ten females, aged 23-52 years, participated. In each, hearing thresholds were measured at frequencies from 250 Hz to 8000 Hz (1) with the head uncovered and ears unoccluded, (2) while wearing the hood, and (3) while fitted with the three earmuffs, unvented and vented. The attenuation achieved with the seven devices was derived by subtracting the unoccluded from the protected thresholds, at each frequency. In Part II, sound level measurements were made during the transfer of pressurized air at twenty-two positions within the Diving Research and Diving Training Facilities of DRDC Toronto.

Results and Conclusions: For each of the seven devices, attenuation increased with frequency, peaking at either 4000 Hz or 6300 Hz. The highest observed attenuation values for the Peltor 10A, Viking, and Moldex M2 earmuffs and the hood were 37.9 dB, 35.9 dB, 42.9 dB, and 26.7 dB, respectively. The difference due to gender was 2 dB on average. Although gender was a significant factor, the impact was relatively small. The effect of venting the earmuffs was apparent below 1000 Hz, ranging from a decrease in attenuation of 5 dB for the Moldex M2 to as much as 17 dB for the Peltor 10A and Viking muffs. The observed difference could not be explained by the size of the vent which was approximately the same across devices. An analysis of the attenuated noise levels indicated that personnel might be at risk of acquiring a noise-induced hearing loss at 250 Hz or 500 Hz in selected areas of the facilities, if they wore the hood or any of the three vented earmuffs. Attenuated levels in these areas ranged from 87.6 dB SPL to 100.9 dB SPL, exceeding Treasury Board guidelines for safe exposures for an 8-hour duration. However, taking into account the short exposures for the divers, it was determined that personnel would be adequately protected.

Sommaire

Risque de perte auditive due au bruit associé aux plongées expérimentales réalisées dans l'installation hyperbare des Forces canadiennes

Sharon M. Abel; Ann Nakashima; Douglas Saunders; Gary Bures; RDDC Toronto TR 2012-084; R&D pour la défense Canada – Toronto. October2012.

Introduction : La présente étude a été réalisée à la suite d'une demande de soutien aux opérations/au développement, à l'ingénierie et aux évaluations (STO/DEE) formulée par le SMA (Mat) relativement à la collecte de données sur le risque de perte auditive due au bruit chez les plongeurs des Forces canadiennes participant à des exercices de plongée expérimentale menés en installation hyperbare. Au début de ces exercices, de l'air pressurisé est introduit dans la chambre de plongée de l'installation hyperbare par un procédé audible. Comme le niveau sonore observé dans les zones adjacentes peut poser un risque d'atteinte auditive, le port d'équipement de protection auditive est obligatoire. Le plongeur en alerte porte normalement une cagoule isothermique en néoprène. Le port d'une protection auditive soulève des préoccupations en raison du risque de barotraumatisme de l'oreille, dans lequel l'incapacité à équilibrer la pression dans l'oreille moyenne et l'oreille externe en fonction des variations de la pression atmosphérique peut entraîner une rupture du tympan. Les barotraumatismes de l'oreille peuvent être évités par le perçage d'un petit orifice de ventilation dans les cache-oreilles afin de permettre l'entrée d'air ambiant dans le conduit auditif externe. Les orifices de ventilation pourraient en contrepartie réduire le niveau d'atténuation sonore de l'équipement de protection auditive.

Méthodes : L'étude, qui comportait deux volets, s'est déroulée à Recherche et développement pour la défense Canada – Toronto (RDDC Toronto). Le premier volet visait à mesurer le niveau d'atténuation sonore associé à l'équipement de protection auditive actuellement employé par les plongeurs de la Marine. Le port des serre-tête antibruit Peltor H10A, Howard Leight Viking et Moldex M2 (avec et sans orifices de ventilation) de même que le port de la cagoule isothermique en néoprène ont été étudiés chez dix hommes et dix femmes de 23 à 52 ans. Les seuils d'audition ont été mesurés chez tous les participants, à des fréquences se situant entre 250 Hz et 8 000 Hz, selon les paramètres suivants : 1) tête découverte et oreilles non occluses; 2) port de la cagoule isothermique; 3) port des trois modèles de serre-tête antibruit, avec ou sans orifices de ventilation. Le niveau d'atténuation du bruit obtenu pendant les sept scénarios de protection auditive a été calculé en soustrayant le seuil auditif mesuré sans occlusion du seuil avec protection, pour chaque fréquence. Le second volet consistait à mesurer le niveau sonore ambiant observé à vingt-deux endroits dans les installations de recherche et d'entraînement en plongée de Recherche et développement pour la défense Canada – Toronto pendant l'introduction d'air pressurisé dans la chambre de plongée.

Résultats et conclusions : Dans chacun des sept scénarios de protection, le niveau d'atténuation sonore augmentait avec la fréquence pour atteindre son maximum à 4 000 Hz ou à 6 300 Hz. Le niveau d'atténuation maximal observé pour les serre-tête antibruit Peltor 10A, Viking et Moldex M2 et pour la cagoule isothermique s'établissait à 37,9 dB, 35,9 dB, 42,9 dB et 26,7 dB, respectivement. En moyenne, la différence attribuable au sexe était de 2 dB; même s'il s'agissait

d’un facteur significatif, le sexe n’a eu que des répercussions minimes sur les résultats. Les répercussions du perçage d’orifices de ventilation ont pu être observées sous 1 000 Hz; la réduction du niveau d’atténuation sonore était de 5 dB pour le protecteur Moldex M2 et pouvait atteindre 17 dB pour les protecteurs Peltor 10A et Viking. Cette différence ne pouvait être expliquée par la taille des orifices de ventilation, qui était semblable d’un protecteur auditif à l’autre. Une analyse des niveaux sonores atténués a révélé que le port de la cagoule ou des trois protecteurs dotés d’orifices de ventilation pourrait exposer le personnel à un risque d’atteinte auditive à 250 Hz ou à 500 Hz dans les installations, à certains endroits où le niveau sonore atténué se situait entre 87,6 dB SPL et 100,9 dB SPL. À ces endroits, les niveaux sonores atténués excédaient les limites d’exposition sécuritaire établies dans les Lignes directrices du Conseil du Trésor pour une exposition de 8 heures; cependant, en raison de la courte durée de l’exposition des plongeurs, il a été déterminé que le personnel serait adéquatement protégé.

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Acknowledgements

This study was conducted in response to a request for Support to Operations / Support to Development Engineering and Evaluation (STO/DEE) regarding the use of ear defenders in Canadian Forces hyperbaric facilities. The work was funded by the Defence Research and Development Canada – Toronto Agility Fund. The authors are indebted to the men and women who volunteered to participate.

1 Introduction

1.1 Background

Continuous unprotected exposure to steady-state noise levels in excess of 87 dBA (decibels, A-weighted; DOJ 2009) or impulse noise exceeding 140 dB (decibels) peak (ISO, 1990) will result in a hearing loss (Abel, 2005). Hearing impairment may be reduced either by reducing the level of the noise at the source or by using personal hearing protection devices. Since reduction at the source is difficult and costly to achieve (Sheen and Hsiao, 2007), the cornerstone of hearing conservation programs, both civilian and military, is the wearing of protective earplugs and earmuffs (Berger, 2000). Conventional passive level independent ear plugs and muffs reduce sounds by the same amount regardless of their level. High frequencies are reduced more than low frequencies. For muffs, sound attenuation typically increases from about 10 dB at 0.25 kHz (kilohertz) to 35 dB at 1 kHz and then remains fairly constant. In general, plugs provide more low frequency attenuation than muffs. However, the outcome varies widely, depending on the particular device chosen and the goodness of fit in individual users (Abel and Odell, 2006).

Users of hearing protection, whether military members or civilians, are concerned that the wearing of such devices will interfere with the detection and localization of warning sounds and the ability to communicate, thereby compromising successful completion of the their job and increasing personal risk (Abel, 2008). In an individual with a hearing loss, the sound attenuation afforded by the hearing protector will add to raised hearing thresholds, increasing the degree of hearing impairment. In both normal and hearing impaired individuals, the wearing of plugs and muffs will interfere with binaural cues, i.e., interaural differences in time-of-arrival and intensity, that are used to distinguish right from left. In addition, both muffs and plugs interfere with spectral cues derived from the filtering effect of the outer ear that enable the discrimination of front from rearward sound sources (Musicant and Butler, 1984; Blauert, 1997; Abel et al., 2007).

A further concern regarding the use of hearing protection devices that applies particularly to individuals employed in naval and air trades is the threat of barotrauma, a rupture of the tympanic membrane (eardrum). Barotrauma results from failure to equalize the pressure across the outer and middle ears (Bentz and Hughes, 2008). As illustrated in Figure 1, these spaces are separated by the eardrum. Normally, their pressures are the same as that of the surrounding air. The enclosed middle ear is vented by the eustachian tube, a soft tissue tube that extends from the back of the nose to the middle ear. During a dive, the atmospheric pressure in the outer ear will normally increase. However, an earplug positioned in the ear canal, a tightly fitting earmuff or a bolus of wax could create a completely enclosed space. As the air pressure rises, the middle ear pressure will increase due to the venting by the eustachian tube but the pressure in the ear canal will remain the same due to the blockage. As a result, the eardrum will bulge outward, causing the volume of the outer ear space to decrease. This can result in pain or a small haemorrhage in the eardrum. If earmuffs are worn, users may attempt to minimize the possible occurrence of barotrauma by drilling a small hole in the earcup (venting) to allow the entry of air in the external ear canal. Venting could, however, reduce the amount of sound attenuation that the device would normally provide.

The following study was conducted in response to a Support to Operations/Support to Development Engineering and Evaluation (STO/DEE) request from ADM (Mat) for information relating to Canadian Forces divers' risk of developing noise-induced hearing loss during simulated dives in hyperbaric facilities. The study was carried out at Defence Research and

Development Canada – Toronto (DRDC Toronto) and involved DRDC Toronto's Diving Research Facility (DRF) and Diving Training Facility (DTF). The DRF comprises three chambers, a living chamber, a transfer chamber, and a dive chamber. The Dive Chamber is used for underwater tests of equipment and procedures. Half the area is flooded with fresh water. The dry half accommodates the team leader and a standby diver who can quickly access the wet half in case of emergency. The Living Chamber contains benches/bunks, a work station and eating area. The Transfer Chamber is used to transfer personnel between the other two chambers. To commence "a dive", the door between the dive and transfer chambers is closed and high pressure air is transferred into the dive chamber to mimic a real-world dive. To "surface from a dive", the chamber atmosphere is vented to decrease the internal pressure. During both evolutions, workers in adjacent areas hear a hissing noise whose level and duration will depend on the depth of the dive and rate of descent/ascent (rate of change in air pressure). In other circumstances such as in response to some emergencies, an increase in air circulation to vent the chamber may be necessary and will also increase the perceived level of noise in the adjacent areas. These evolutions generally take no more than a few minutes. Nonetheless, the noise exposure levels may pose a risk for hearing. The wearing of vented hearing protection earmuffs is mandatory. The standby diver wears only a neoprene wetsuit hood

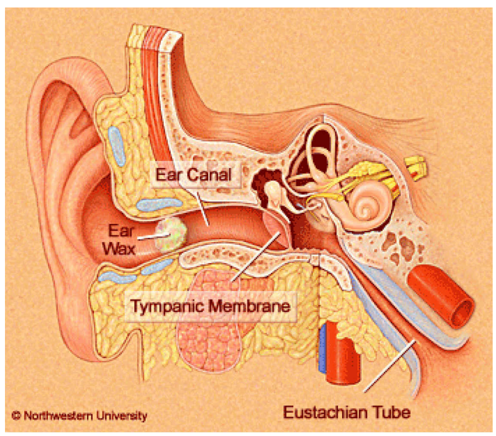

Figure 1 The outer and middle ears separated by the tympanic membrane. From Bentz and Hughes (2008).

1.2 Purpose of the study

An experiment was conducted to determine the amount by which the sound attenuation of three different hearing protection earmuffs currently used by navy divers in the DRF and DTF is reduced by venting. The attenuation provided by the neoprene wetsuit hood worn by the standby diver was also assessed. The amount of sound attenuation achieved with each earmuff and the hood was applied to the level of the noise measured at various positions in each of the chambers of the DRF and DTF to determine whether or not the protectors (not vented and vented) and the hood were sufficient to prevent the development of noise-induced hearing loss. The four devices that were evaluated are shown in Figures 2, 3 and 4. These included the Peltor H10A earmuff (Aearo Company, Indianapolis, IN), the Howard Leight Viking earmuff (Honeywell LLC, San Diego, CA), and the Moldex M2 multi-position earmuff (Moldex-Metric, Inc., Culver City, CA), and a Canadian Forces (CF) issue neoprene wetsuit hood (Whites Manufacturing, Saanichton, BC). The size of the vents were 0.4, 0.4 and 0.5 cm in diameter respectively, and sufficiently deep to penetrate the outer plastic shell.

Figure 2 The Peltor H10A (left), Howard Leight Viking (centre) and Moldex M2 (right) earmuffs.

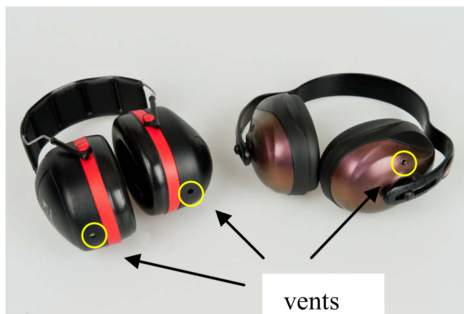

Figure 3 Illustration of vents in the earcups of the Peltor 10A and Moldex M2 earmuffs.

Figure 4 The wetsuit hood.

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2 Methods and materials

The study comprised two parts. The first part was designed to measure the real-ear attenuation at threshold (REAT; ANSI, 2008), hereafter referred to as sound attenuation, of the devices under review. In the second part, measurements were made of the sound levels at various positions within the DRF and DTF during the introduction of pressurized air. The mean attenuation observed for frequencies ranging between 250 Hz and 8000 Hz was subtracted from the noise levels at these frequencies for each of the seven devices to determine whether they were sufficiently hearing protective.

2.1 Part I Sound attenuation of hearing protection devices

2.1.1 Selection of human participants

The protocol was approved in advance by the Human Research Ethics Committee of Defence Research and Development Canada – Toronto (DRDC Toronto). Two groups of 10 males and 10 females, respectively, aged 23-52 years, were recruited with the aid of an email sent to employees of DRDC Toronto and the Canadian Forces Environmental Medicine Establishment (CFEME). Previous studies have shown that females may achieve less sound attenuation than males with both earmuffs and earplugs due to smaller head circumference and smaller cross-sectional diameter of the external ear canal, respectively (Abel et al., 1988; Abel et al., 1990; Berger, 2000). An independent samples t-test (Daniel, 1983) applied to the ages for males and females indicated that the two groups did not differ statistically. Prior to inclusion in the study, volunteers were screened by telephone by a member of the research team for a history of ear disease, hearing loss and tinnitus, claustrophobia and difficulty concentrating over a 2-hour period. Those who passed the screening criteria signed a Consent Form that described the study prior to undergoing a hearing test to ensure that their pure-tone air conduction thresholds in each ear were normal, i.e., no greater than 20 dB HL (decibels, hearing level), i.e., no more than a slight hearing loss at 500, 1000, 2000 and 4000 Hz (Yantis, 1985).

2.1.2 Procedure

Participants were tested individually while seated at the centre of an IAC Series 1200 double-walled, semi-reverberant sound proof booth (International Acoustics Company, Inc., Bronx, NY) with inner dimensions of 3.5 (L) × 2.7 (W) × 2.3 (H) metres that met the requirements for hearing protector testing specified in American National Standard S12.6-2008 (ANSI, 2008). The ambient noise was less than the maximum permissible for audiometric test rooms specified in American National Standard S3.1-1999 (ANSI, 1999).

Binaural hearing thresholds were assessed under eight experimental conditions, in which the ears were unoccluded and the head was bare, the ears were fitted bilaterally with three hearing protection earmuffs, unvented and vented, or the head was fitted with a neoprene wetsuit hood. The unoccluded (bareheaded) ear condition was presented first followed by the seven protected conditions, the order of the latter counterbalanced across subjects to equalize practice/fatigue. Participants were given verbal instructions for fitting the earmuffs before doing so themselves. Fits were checked by a trained technician to ensure that the earmuffs were well seated. This is a variation of Method A (Experimenter-Supervised Fit) described in American National Standard 12.6-2008 (ANSI, 2008). The sound attenuation provided by each of the seven devices was derived by subtracting the hearing threshold obtained for the ears unoccluded (control) condition from the hearing thresholds obtained for each of the protected conditions, at each sound frequency tested (see below).

Hearing thresholds were measured once for each of eight one-third octave noise bands, centred at eight frequencies including 250, 500, 1000, 2000, 3150, 4000, 6300 and 8000 Hz, in each of the eight conditions. A variation of Békésy tracking was used (Brunt, 1985). For each threshold determination, the stimulus was pulsed continuously at a rate of 2.5 per second. The pulse duration was 250 milliseconds including a rise/decay time of 50 milliseconds. Participants were instructed to depress an on/off push-button switch whenever the pulses are audible, and to release the switch when they can no longer be heard. The sound level of consecutive pulses was increased in steps of 1 dB until the switch was depressed and then decreased at the same rate of change until the switch was released. This tracking trial was terminated after a minimum of eight alternating intensity excursions with a range of 4 to 20 dB. Hearing thresholds were defined as the average sound level of the eight final peaks and valleys.

The one-third octave noise bands, were presented free-field over a set of three loudspeakers (Celestion DL10; Maidstone, Kent, UK) positioned to create a uniform sound field (Giguère and Abel, 1990). The range of levels that were used did not exceed the levels designated by the Treasury Board as safe for human hearing without protection, i.e., the energy equivalent of 87 dBA continuously for 8 hours (DOJ, 2009). Levels were set and checked prior to testing each participant to preclude the possibility of accidental overstimulation.

2.1.3 Data analysis

The dataset for each subject consisted of hearing thresholds for each of eight frequencies, under each of the eight experimental conditions, as well as the derived sound attenuation scores for the protective devices. A repeated measures analysis of variance (Daniel, 1983) was applied to the attenuation scores to assess the significance of differences in outcome among the devices tested, at each sound frequency, for males and females. Of particular interest was the effect of earmuff venting

2.2 Part II Noise measurements

2.2.1 Procedure

Noise measurements were made in both the DRF and DTF of DRDC Toronto. The layouts of these two facilities are shown in Figure 5. The numerals 1-22 indicate the measurement positions. A description of these positions is given in Table 1. The measurements were made using a sound level meter (Larson Davis, Inc., Provo, Utah) in a one-minute time-logging mode. The pumps that are normally used to transfer high-pressure air into the chambers of the facilities were run to simulate the ambient noise experienced during a dive. However, the doors were left slightly ajar to prevent the air pressure from building up.

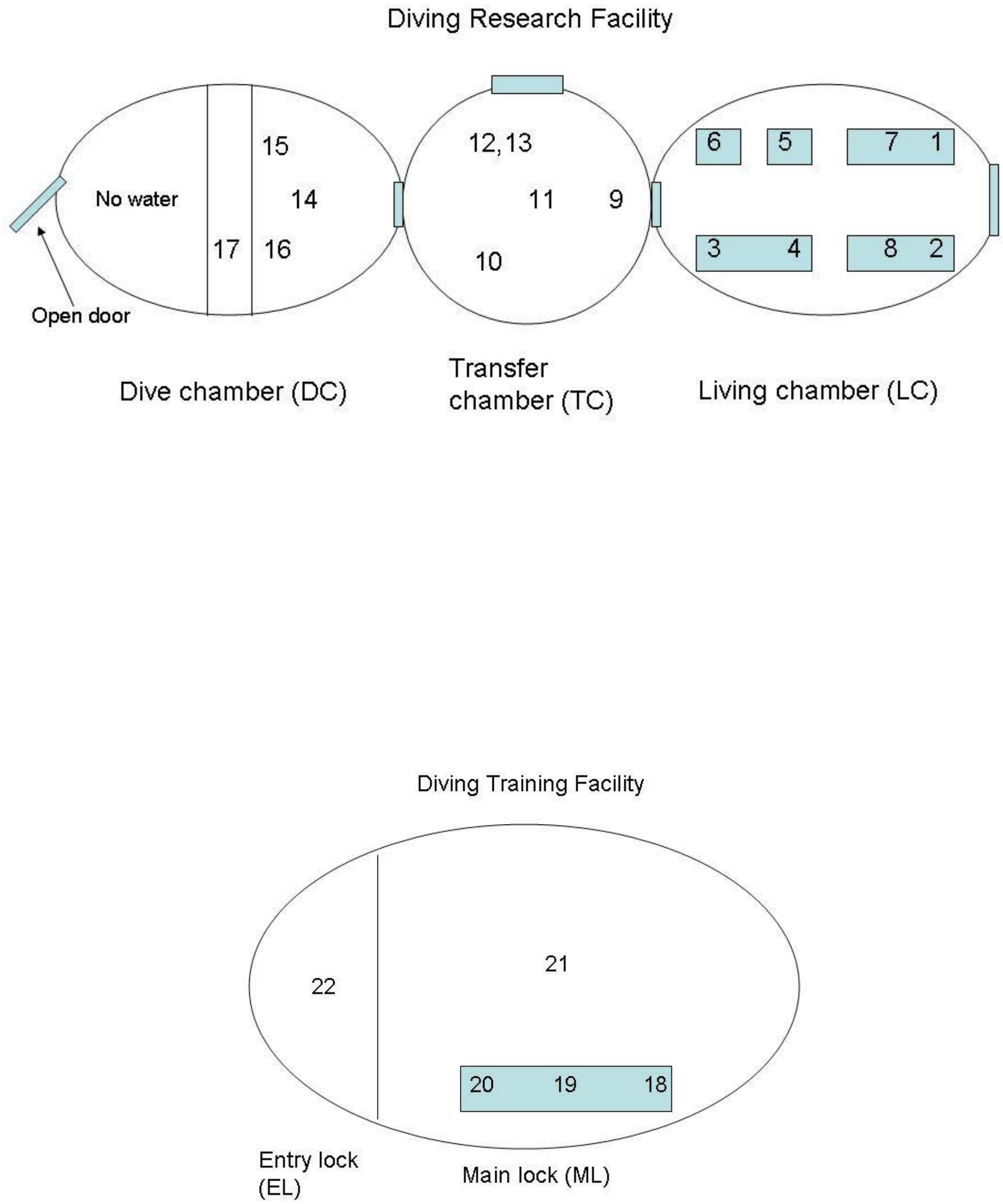


Figure 5 Schematic of the Diving Research and Diving Training Facilities at DRDC Toronto.

Table 1 Positions at which noise measurements were made in the Diving Research Facility (DRF) and Diving Training Facility (DTF).

DRF Living Chamber	DRF Transfer Chamber	DRF Dive Chamber	DTF
1 lying on cot	9 lying on floor	14 standing	18 sitting
2 lying on cot	10 standing	15 sitting beside tank	19 sitting
3 sitting on cot	11 standing	16 standing beside tank	20 sitting
4 sitting on cot	12 standing nr comms control	17 safety diver seat	21 standing
5 sitting on cot	13 sitting at comms center		22 standing
6 sitting on cot			
7 sitting on cot			
8 sitting on cot			

3 Results

3.1 Hearing protector attenuation

The mean attenuation observed with each of the seven devices is shown in Table 2, separately for males (M) and females (F), and averaged (A) across gender groups. Generally, attenuation increased from 250 Hz to 4000 Hz and then remained fairly stable. The lowest average values observed at 250 Hz ranged from -0.1 dB (Hood) to 21.9 dB (Peltor 10A, not vented). The highest average values achieved ranged from 26.7 dB (Hood at 6300 Hz) to 42.9 dB (Moldex M2, vented at 4000 Hz). A repeated measures analyses of variance (Daniel, 1983) was applied to the attenuation scores for the three muffs to assess the significance of differences due to earmuff, venting, frequency and gender. The results showed statistically significant main effects ($p<0.01$ or better) for gender, protector, venting, and frequency, as well as three significant two-way interactions ($p<0.001$ or better) for protector by venting, protector by frequency, and venting by frequency, and two significant three-way interactions ($p<0.02$ or better) for protector by frequency by gender and protector by venting by frequency.

Averaged across protector, venting and frequency, males achieved 2 dB more attenuation than females. The two significant three-way interactions are shown in Figures 6 and 7. In Figure 6, results are shown for each of the three muffs, averaged across venting, separately for males (M) and females (F). In Figure 7, results are shown for the three muffs, not vented (NV) and vented V), averaged across gender groups. For each of the three muffs, the vented values were always relatively less than the unvented values. This was particularly apparent for the Peltor 10A and Viking muffs at 250 Hz and 500 Hz, where the differences ranged from 14-17 dB. At 1000 Hz the differences were 8 and 6 dB, respectively. For the Moldex M2 muff, the differences at all three frequencies were 5-6 dB.

Table 2 Sound attenuation (dB) observed for the Hood, and the Peltor 10A (P), Viking (V) and Moldex M2 (M) earmuffs, not vented (NV) and vented (V).

		Frequency (Hz)							
Device	G	250	500	1000	2000	3150	4000	6300	8000
Hood	M	0.3 (3.3)*	-2.6 (4.9)	-3.4 (4.0)	5.5 (5.8)	18.4 (5.3)	22.7 (4.1)	27.8 (7.2)	26.3 (6.9)
	F	-0.5 (4.5)	-1.0 (2.4)	0.4 (4.9)	5.5 (5.4)	15.0 (4.4)	18.6 (3.9)	25.5 (4.5)	23.4 (5.4)
	A	-0.1 (3.9)	-1.8 (3.9)	-1.5 (4.8)	5.5 (5.4)	16.7 (5.1)	20.7 (4.4)	26.7 (6.0)	24.9 (6.2)
PNV	M	23.2 (2.0)	36.7 (3.2)	35.6 (3.4)	35.6 (3.4)	37.7 (3.3)	39.5 (3.2)	37.9 (3.6)	37.7 (3.7)
	F	20.6 (5.1)	34.7 (4.5)	34.7 (4.0)	31.4 (2.8)	33.7 (2.9)	36.4 (2.0)	37.0 (3.2)	37.0 (3.4)
	A	21.9 (4.0)	35.7 (3.9)	35.1 (3.7)	33.5 (3.7)	35.7 (3.7)	37.9 (3.1)	37.4 (3.3)	37.3 (3.5)
PV	M	8.3 (2.2)	18.5 (3.4)	26.4 (2.6)	33.8 (2.8)	36.7 (5.0)	39.1 (3.2)	37.7 (1.8)	37.5 (2.6)
	F	7.0 (4.4)	18.2 (3.2)	27.3 (3.6)	30.3 (2.4)	33.6 (3.3)	35.1 (3.0)	34.0 (5.4)	32.1 (6.2)
	A	7.6 (3.5)	18.3 (3.2)	26.8 (3.1)	32.1 (3.1)	35.1 (4.4)	37.1 (3.7)	35.9 (4.4)	34.8 (5.4)
VNV	M	21.1 (4.6)	31.3 (4.0)	34.8 (2.8)	32.0 (1.9)	32.8 (3.8)	34.2 (3.4)	36.6 (2.5)	35.9 (3.3)
	F	20.3 (4.5)	29.1 (3.4)	35.5 (2.7)	30.4 (2.6)	32.1 (2.8)	32.2 (1.6)	35.1 (3.1)	35.0 (3.4)
	A	20.7 (4.4)	30.2 (3.8)	35.2 (2.7)	31.2 (2.4)	32.5 (3.3)	33.2 (2.8)	35.9 (2.8)	35.4 (3.3)
VV	M	5.0 (1.5)	18.1 (3.3)	29.4 (3.4)	31.3 (1.7)	31.9 (2.4)	32.8 (3.1)	37.4 (2.6)	37.0 (3.4)
	F	3.6 (4.6)	15.0 (2.7)	28.8 (1.8)	27.9 (2.7)	29.8 (2.8)	31.1 (2.0)	33.9 (3.4)	33.1 (4.6)
	A	4.3 (3.4)	16.6 (3.3)	29.1 (2.7)	29.6 (2.8)	30.9 (2.7)	31.9 (2.7)	35.7 (3.4)	35.1 (4.4)
MNV	M	15.8 (2.0)	25.5 (4.0)	32.9 (4.6)	34.6 (3.5)	43.0 (7.2)	42.4 (2.7)	41.5 (3.2)	40.9 (5.0)
	F	15.9 (6.2)	24.6 (3.3)	32.4 (4.4)	32.4 (3.2)	41.4 (4.2)	42.5 (2.1)	37.7 (4.8)	36.3 (6.4)
	A	15.9 (4.5)	25.0 (3.6)	32.7 (4.4)	33.5 (3.4)	42.2 (5.8)	42.5 (2.4)	39.6 (4.4)	38.6 (6.1)
MV	M	8.8 (2.1)	20.1 (3.2)	27.5 (2.8)	33.7 (3.0)	42.3 (3.2)	43.0 (2.6)	41.4 (3.2)	41.1 (2.6)
	F	10.0 (4.2)	17.0 (3.4)	28.3 (3.2)	31.7 (1.6)	40.7 (2.9)	42.7 (3.5)	38.1 (3.7)	37.8 (5.4)
	A	9.4 (3.3)	18.6 (3.6)	27.9 (3.0)	32.7 (2.6)	41.5 (3.1)	42.9 (3.0)	39.8 (3.7)	39.4 (4.5)

*Mean (standard deviation); Males (M), N=10; Females (F), N=10; Average (A), N=20

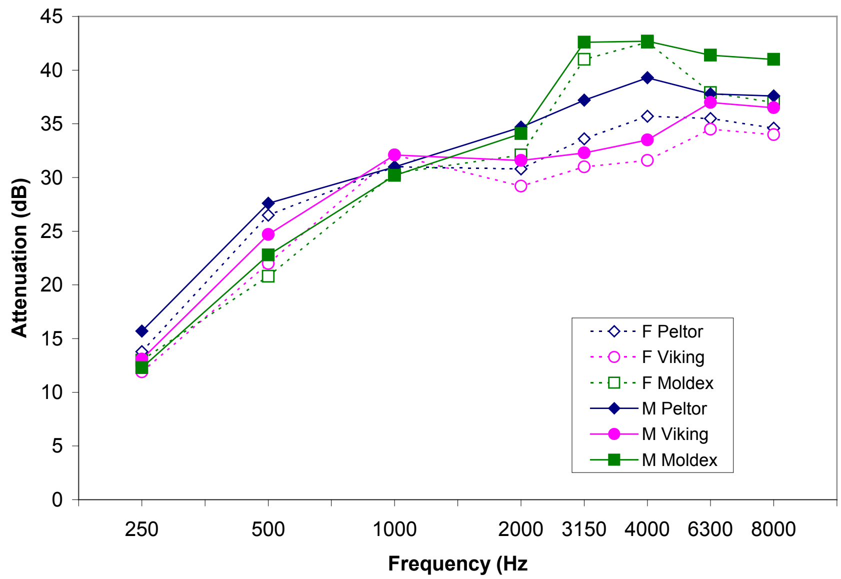


Figure 6 Effect of combinations of gender, hearing protector, and sound frequency on achieved attenuation. (M-male; F-female)

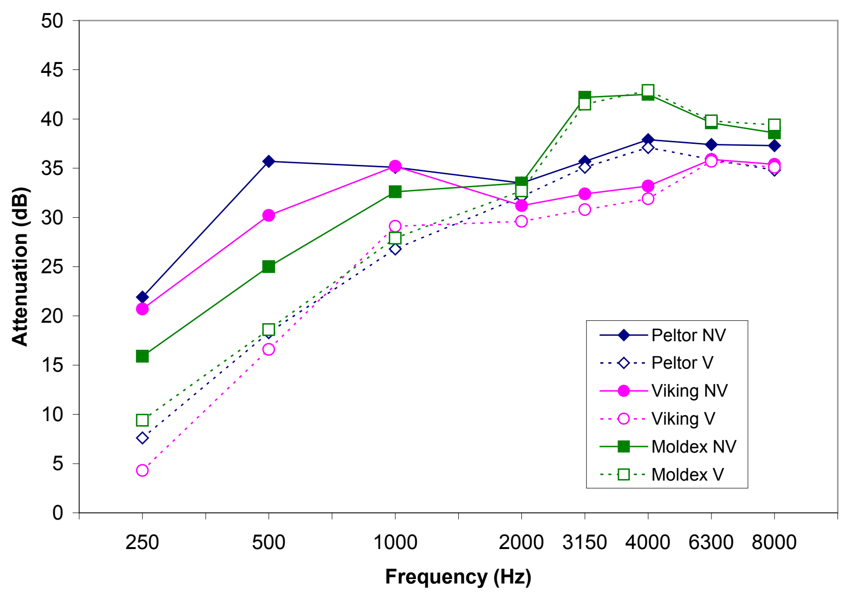


Figure 7 Effect of combinations of hearing protector, venting and sound frequency on achieved attenuation. (V-vented; NV-not vented)

3.2 Noise measurements

The overall noise levels, unweighted (decibels sound pressure level, dB SPL) and A-weighted (dBA) observed in the Diving Research and Diving Training Facilities are given in Table 3. A-weighting models the relatively poorer sensitivity of the human ear to low and high frequencies compared with the middle or speech frequencies. A-weighted values will be lower than the unweighted values. It can be seen from the table that the overall levels are equal to or exceed 87 dBA, the level at which Treasury Board recommends the wearing of hearing protection for 8-hr exposures (DOJ, 2009). The relatively high overall unweighted level in the DRF Transfer Chamber compared with the Living and Dive chambers was due to a tonal component at 160 Hz which ranged from 103-106 dB SPL across the five measurement positions in this area.

Table 3 Overall noise levels observed in the DRF and DTF.

	Unweighted Levels (dB SPL)	A-weighted Levels (dBA)
Diving Research Facility		
Living Chamber	94 – 100	93-99
Transfer Chamber	103 – 110	94-98
Dive Chamber	94 - 99	92-97
Diving Training Facility		
Main Lock	113 – 114	112 – 113
Entry Lock	88	87

The energy spectra for one-third octave bands with centre frequencies ranging from 31.5 Hz to 10,000 Hz are presented in Figures 8-11 for each of twenty-two measurement positions (POS 1-POS 22) selected for study in the five chambers of the two diving facilities. In accordance with common practice, octave band measurements are made in dB SPL. Overall values in dB SPL and dBA have been included for comparison. Differences between dB SPL and dBA values are frequency dependent. They are the same for frequencies at or above 1 kHz. At 500 Hz 87 dBA corresponds to about 90 dB SPL and at 250 Hz to 92 dB SPL. A horizontal red line at 87 dB SPL was added to each of the figures to highlight observed levels that are close to or exceed the criterion for use of hearing protection. The data show that the energy spectra at the various positions within each chamber were highly similar. Exceptions noted were at 250 Hz in the Living Chamber, at 125 Hz in the Transfer Chamber, and at 500 Hz in the Dive Chamber of the DRF. The levels measured in the Entry Lock were relatively lower than those measured at positions in the Main Lock of the DTF. Values exceeding 87 dB SPL were evident in the DRF Living Chamber at 6300 Hz to 10000 Hz, at Positions 3-6, the DRF Dive Chamber at 500 Hz at Position 14, and all positions in the DTF Main Lock at 125 Hz to 10,000 Hz.

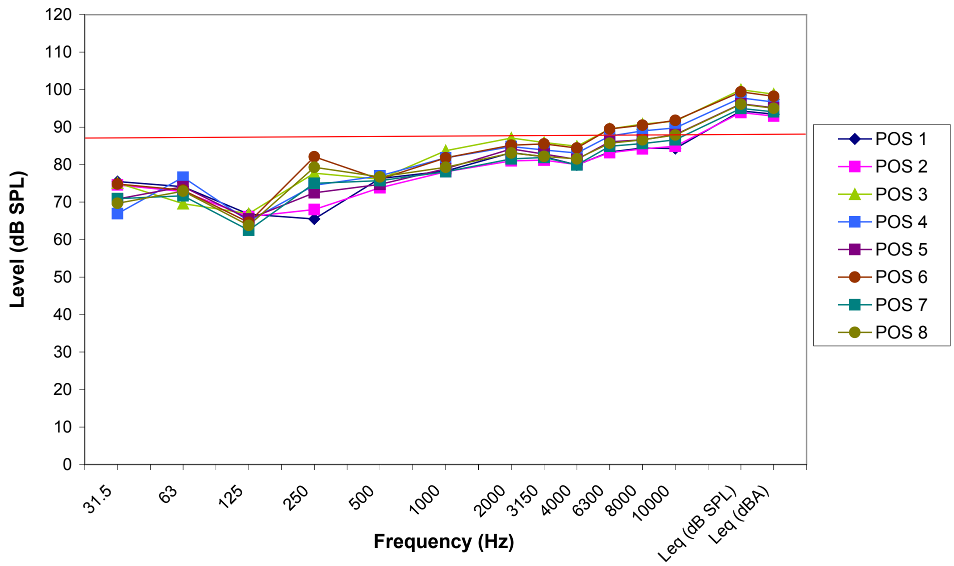


Figure 8 Energy spectra of the noise at eight positions (POS 1-POS 8) in the Living Chamber of the DRF.

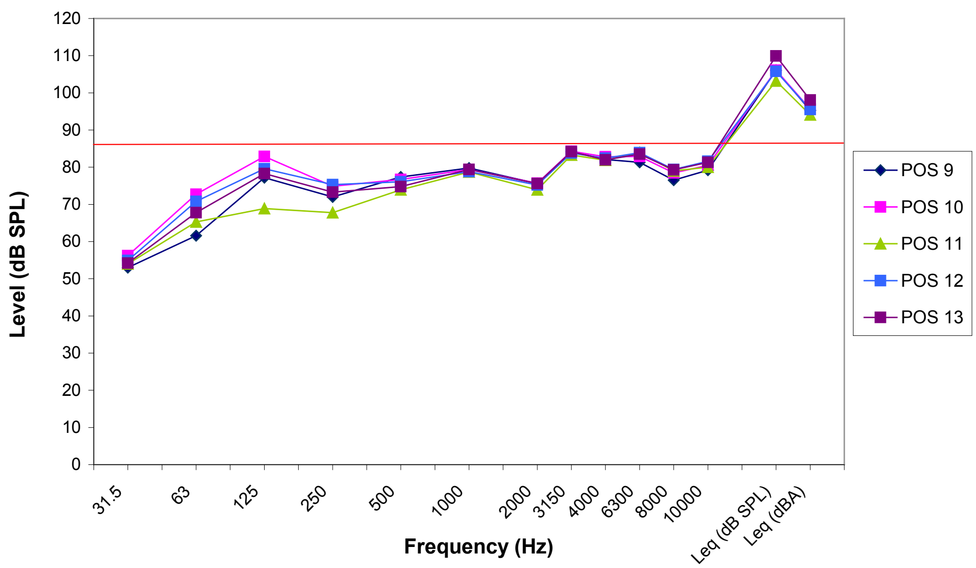


Figure 9 Energy spectra of the noise at five positions (POS 9 – POS 13) in the Transfer Chamber of the DRF.

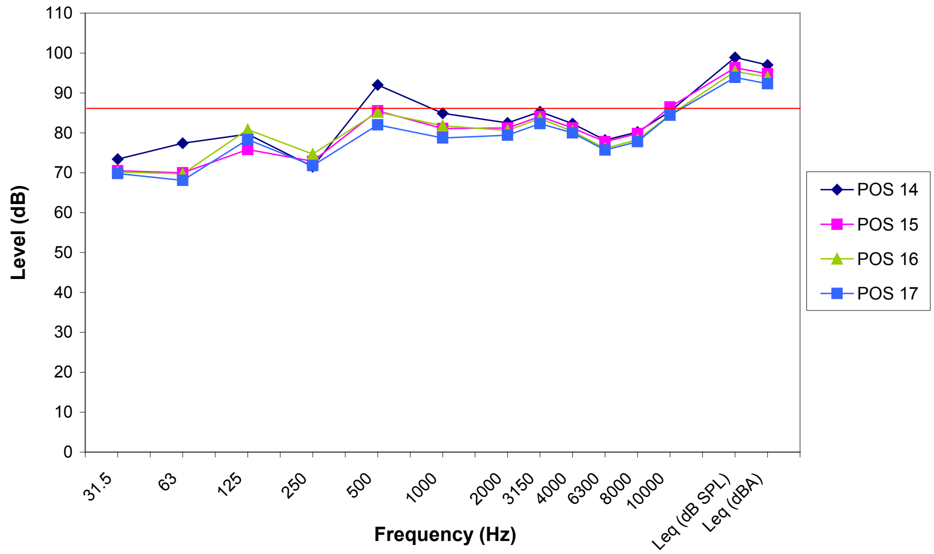


Figure 10 Energy spectra of the noise at four positions (POS 14 – POS 17) in the Dive Chamber of the DRF.

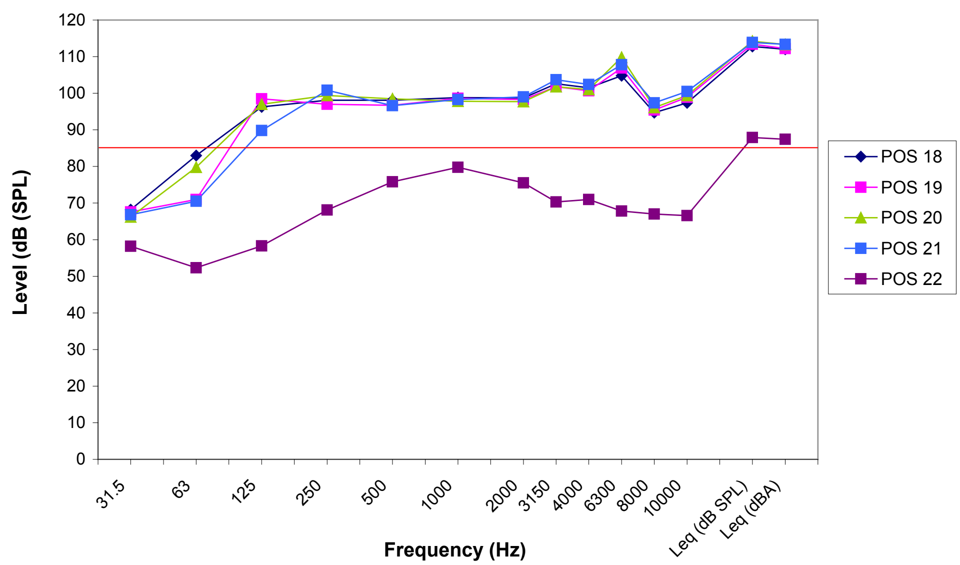
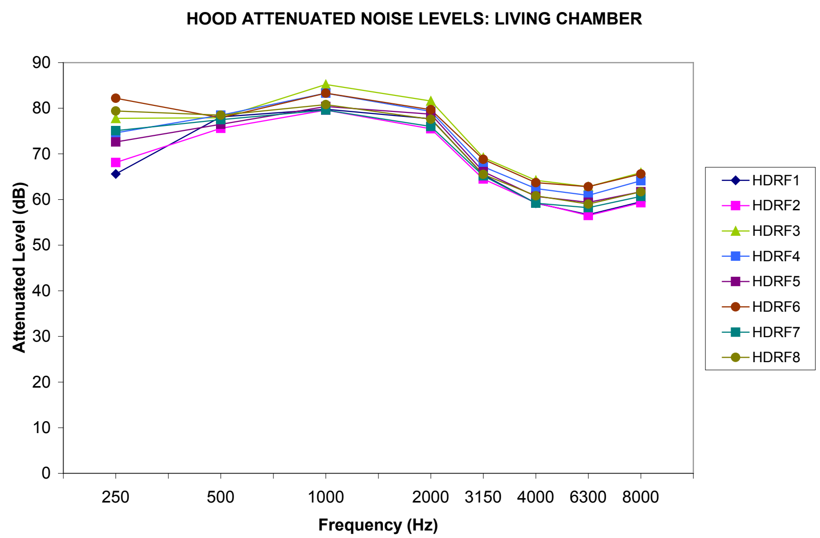


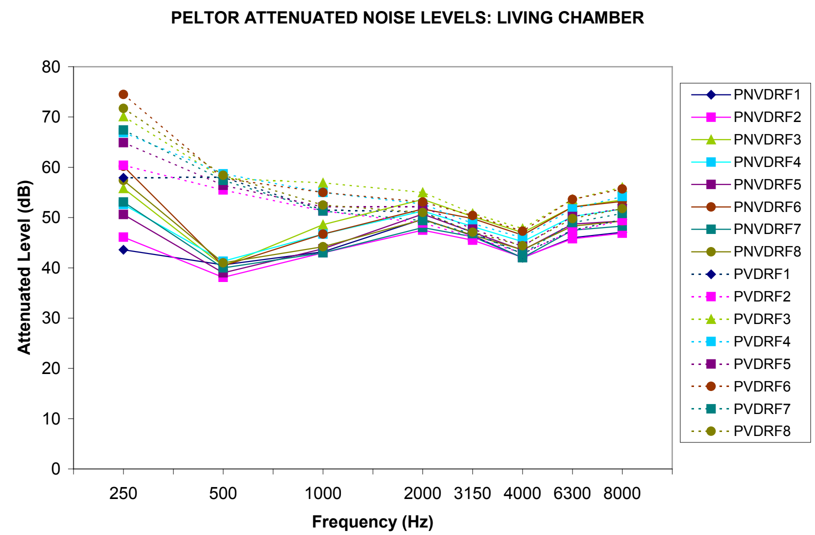
Figure 11 Energy spectra of the noise at five positions (POS 18 – POS 22) in the DTF.

3.3 Attenuation of noise levels in the DRF and DTF

In order to determine whether the earmuffs, whether unvented or vented, and the hood were sufficiently protective, the mean attenuation values (averaged across males and females) were subtracted from the noise levels measured at each of the twenty-two positions in the DRF and DTF, at frequencies ranging from 250 Hz to 8000 Hz. The outcomes are shown in Figure 12, by device and chamber. The earmuff unvented protected levels are joined by solid lines; vented protected values by dotted lines.

The figures show that the protected noise levels for the various measurement positions within a chamber were quite similar. As expected from the protector attenuation data presented above, differences due to venting were apparent for frequencies below 2000 Hz. For the Living and Transfer chambers in the DRF and the Entry Lock in the DTF (Pos 22), the protected noise levels were well below 90 dB SPL. However, values were at or exceeded 87 dB SPL in the Dive Chamber of the DRF when the hood was worn (POS 14, 500 Hz), and in the Main Lock of the DTF when the hood was worn (POS 18-21, 250-2000 Hz), and when any of the three vented earmuffs were worn (POS 18-21, 250 Hz).


HOOD ATTENUATED NOISE LEVELS: LIVING CHAMBER
Attenuated Level (dB)
Frequency (Hz)
HDRF1
HDRF2
HDRF3
HDRF4
HDRF5
HDRF6
HDRF7
HDRF8


PELTOR ATTENUATED NOISE LEVELS: LIVING CHAMBER
Attenuated Level (dB)
Frequency (Hz)
PNVDRF1
PNVDRF2
PNVDRF3
PNVDRF4
PNVDRF5
PNVDRF6
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PVDRF1
PVDRF2
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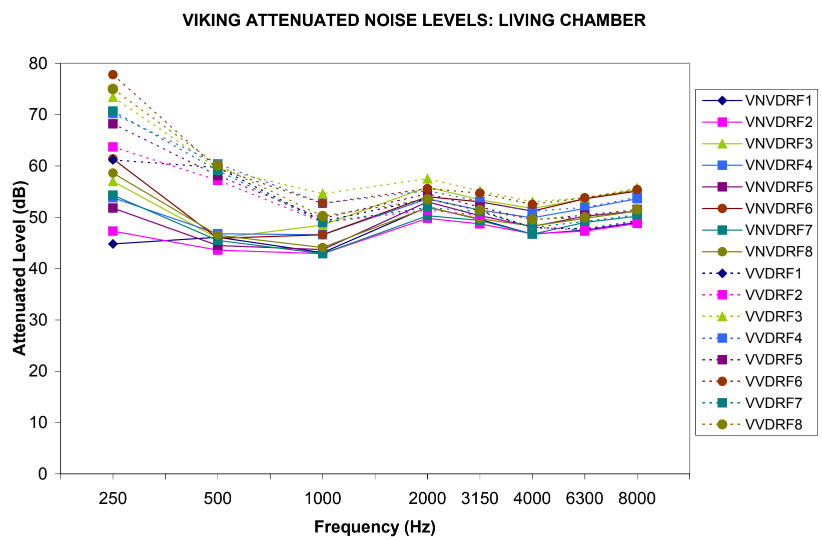
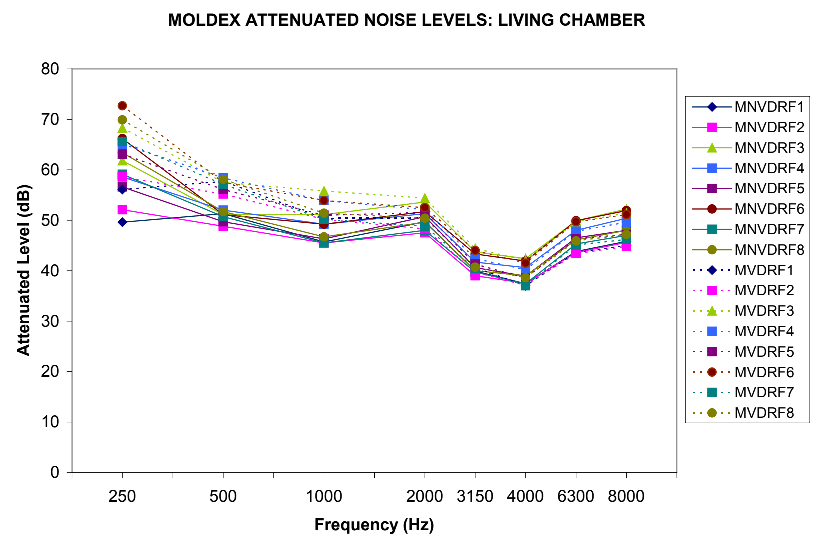
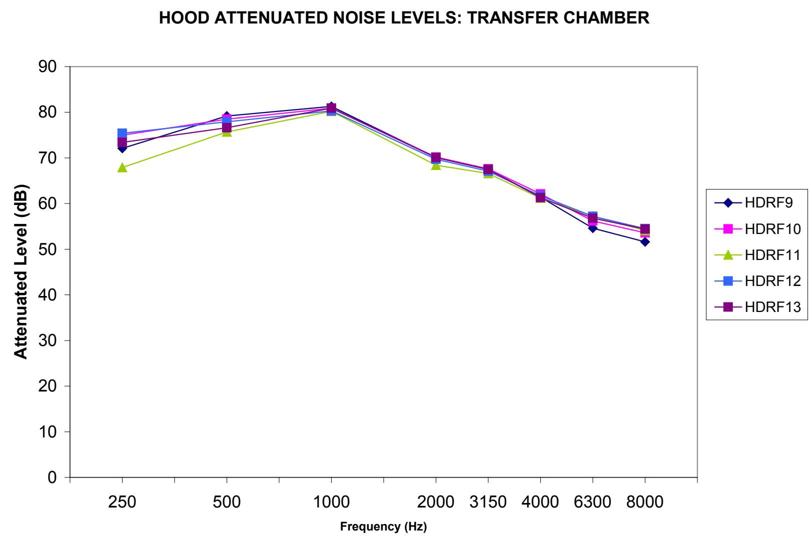
PVDRF7
PVDRF8


VIKING ATTENUATED NOISE LEVELS: LIVING CHAMBER
Attenuated Level (dB)
Frequency (Hz)
VNVDRF1
VNVDRF2
VNVDRF3
VNVDRF4
VNVDRF5
VNVDRF6
VNVDRF7
VNVDRF8
VVDRF1
VVDRF2
VVDRF3
VVDRF4
VVDRF5
VVDRF6
VVDRF7
VVDRF8


MOLDEX ATTENUATED NOISE LEVELS: LIVING CHAMBER
Attenuated Level (dB)
Frequency (Hz)
MNVDRF1
MNVDRF2
MNVDRF3
MNVDRF4
MNVDRF5
MNVDRF6
MNVDRF7
MNVDRF8
MVDRF1
MVDRF2
MVDRF3
MVDRF4
MVDRF5
MVDRF6
MVDRF7
MVDRF8


HOOD ATTENUATED NOISE LEVELS: TRANSFER CHAMBER
Attenuated Level (dB)
Frequency (Hz)
0
10
20
30
40
50
60
70
80
90
250
500
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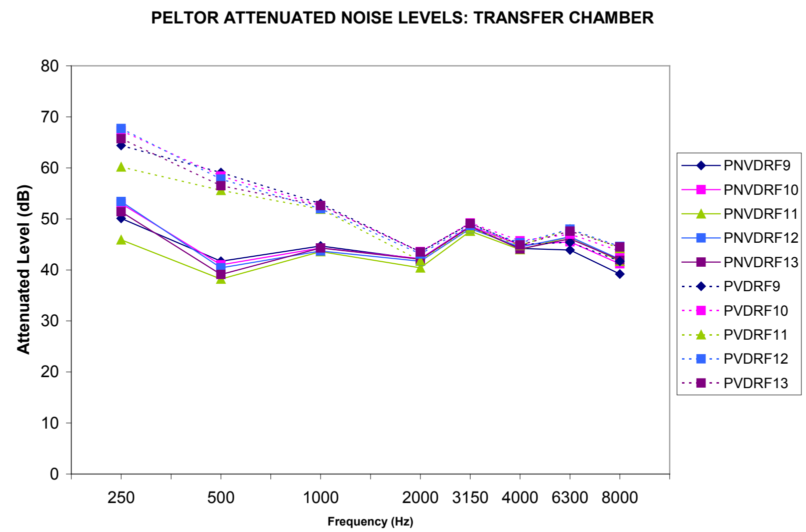
2000
3150
4000
6300
8000
HDRF9
HDRF10
HDRF11
HDRF12
HDRF13


PELTOR ATTENUATED NOISE LEVELS: TRANSFER CHAMBER
Attenuated Level (dB)
Frequency (Hz)
0
10
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70
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250
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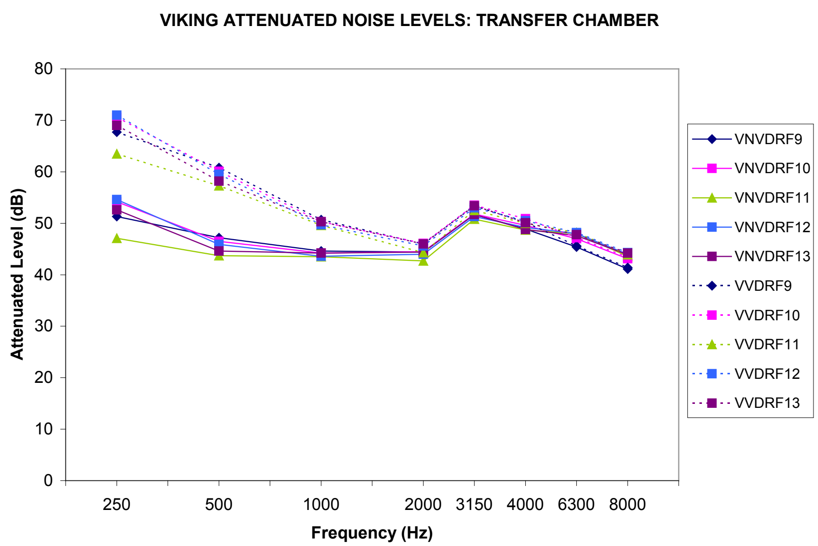
1000
2000
3150
4000
6300
8000
PNVDRF9
PNVDRF10
PNVDRF11
PNVDRF12
PNVDRF13
PVDRF9
PVDRF10
PVDRF11
PVDRF12
PVDRF13


VIKING ATTENUATED NOISE LEVELS: TRANSFER CHAMBER
Attenuated Level (dB)
Frequency (Hz)
0
10
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250
500
1000
2000
3150
4000
6300
8000
VNVDRF9
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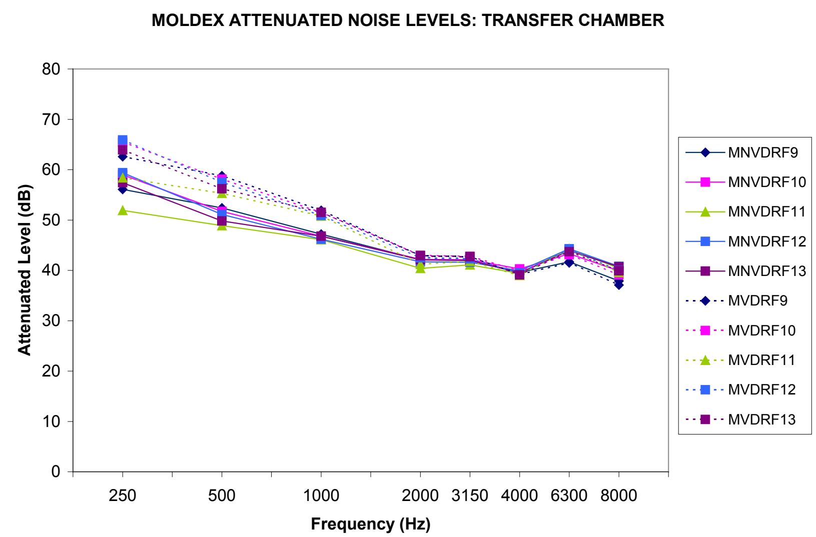
VVDRF12
VVDRF13


MOLDEX ATTENUATED NOISE LEVELS: TRANSFER CHAMBER
Attenuated Level (dB)
Frequency (Hz)
0
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2000
3150
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6300
8000
MNVDRF9
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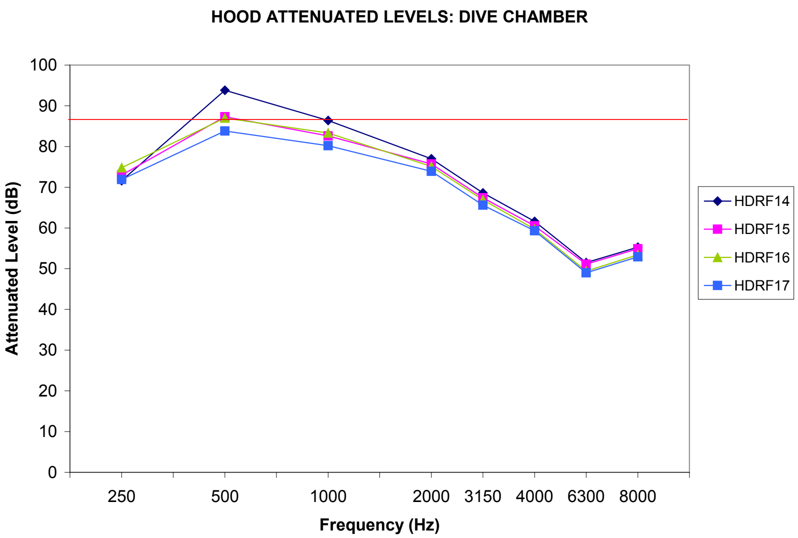
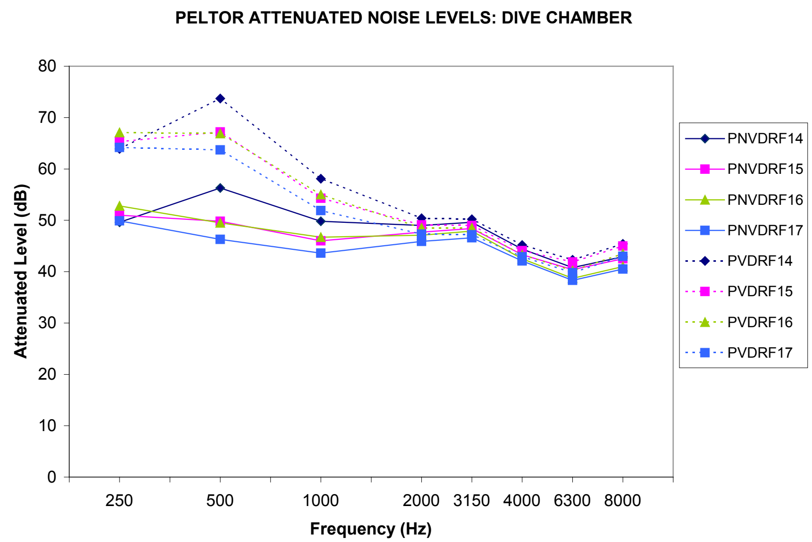
MVDRF12
MVDRF13


HOOD ATTENUATED LEVELS: DIVE CHAMBER
Attenuated Level (dB)
Frequency (Hz)
100
90
80
70
60
50
40
30
20
10
0
250
500
1000
2000
3150
4000
6300
8000
HDRF14
HDRF15
HDRF16
HDRF17


PELTOR ATTENUATED NOISE LEVELS: DIVE CHAMBER
Attenuated Level (dB)
Frequency (Hz)
80
70
60
50
40
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10
0
250
500
1000
2000
3150
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6300
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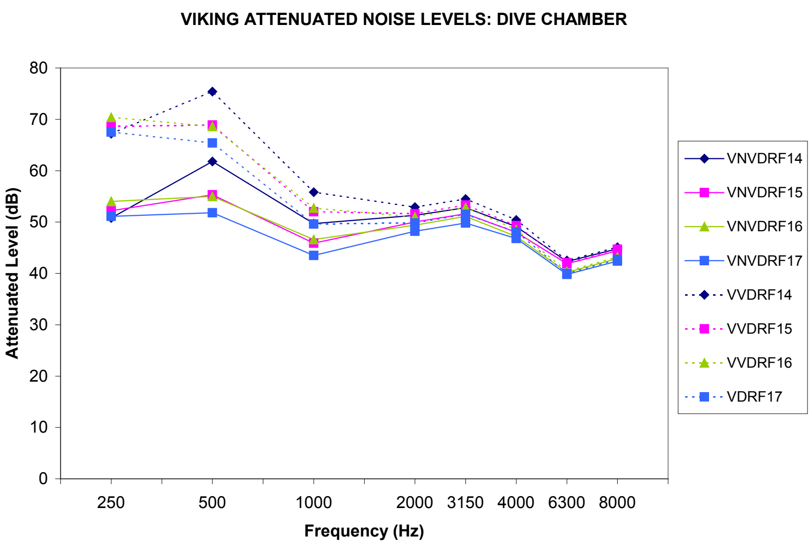
PNVDRF14
PNVDRF15
PNVDRF16
PNVDRF17
PVDRF14
PVDRF15
PVDRF16
PVDRF17


VIKING ATTENUATED NOISE LEVELS: DIVE CHAMBER
Attenuated Level (dB)
Frequency (Hz)
80
70
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250
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2000
3150
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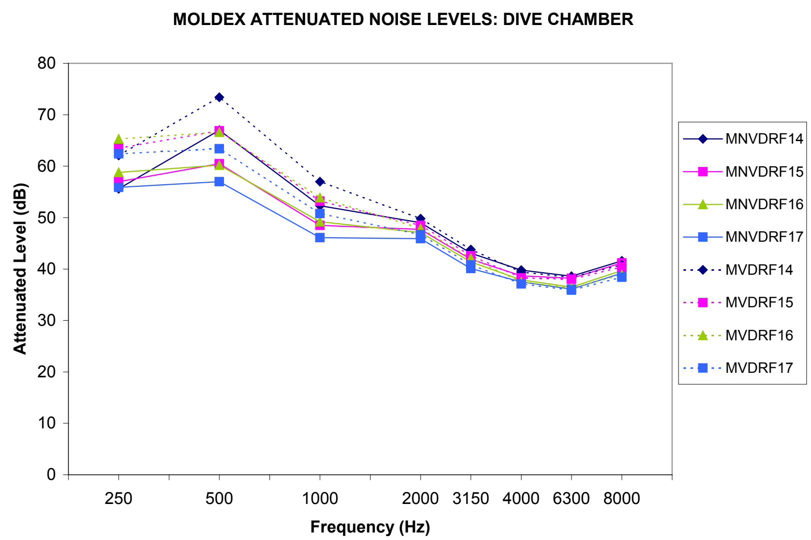
VVDRF14
VVDRF15
VVDRF16
VDRF17


MOLDEX ATTENUATED NOISE LEVELS: DIVE CHAMBER
Attenuated Level (dB)
Frequency (Hz)
80
70
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3150
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6300
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MNVDRF14
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MNVDRF17
MVDRF14
MVDRF15
MVDRF16
MVDRF17

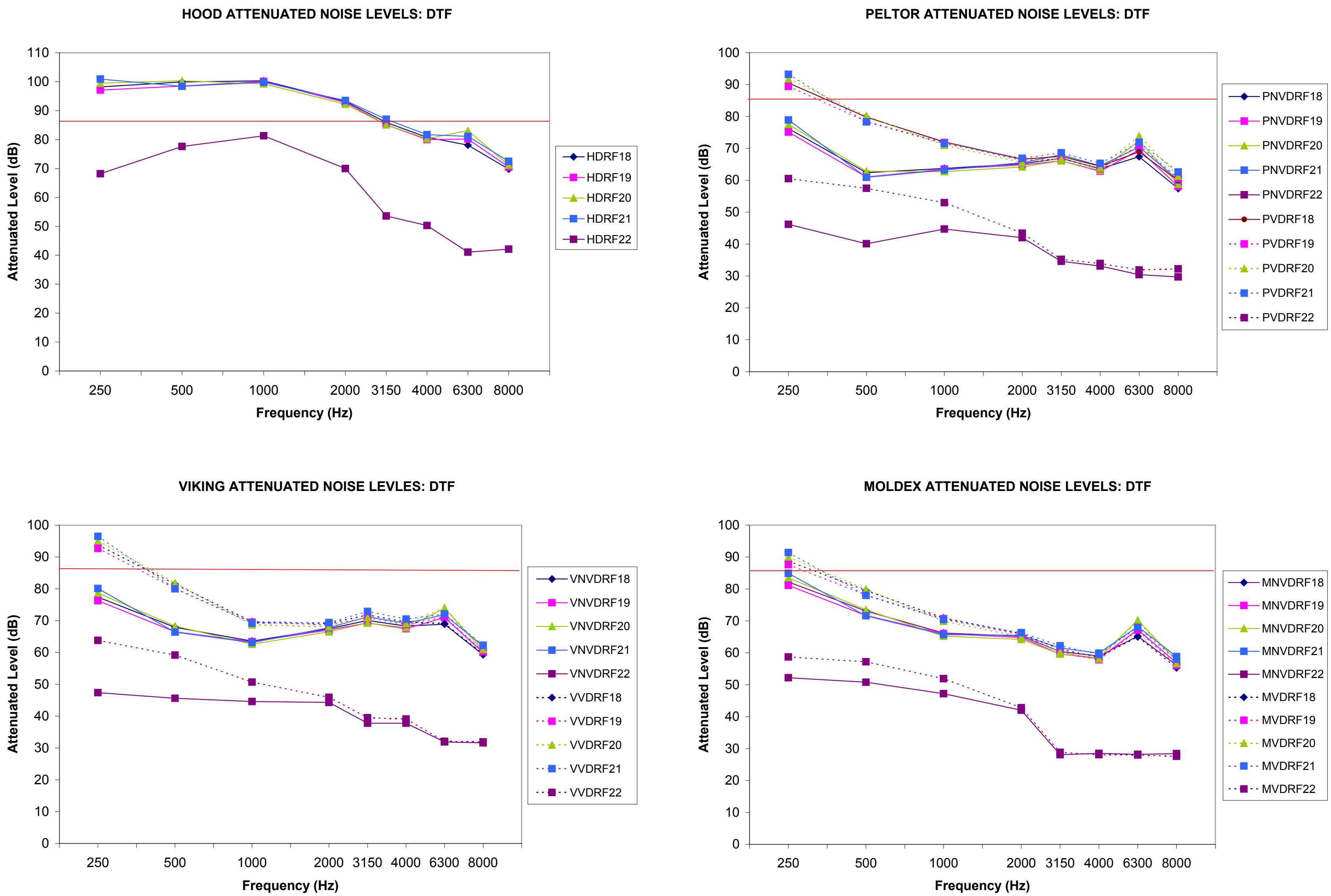

Figure 12 Attenuated noise levels in the DRF and DTF for combinations of measurement position and hearing protector.

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4 Discussion

The experiment described above was conducted to determine the effect of venting on the sound attenuation provided by hearing protective earmuffs that are used in hyperbaric facilities. Venting is the practice of drilling small holes in the outer shell of earmuffs to minimize the possibility of barotrauma during simulated dives. The size of the vents was approximately the same for the three devices tested, ranging from 0.4-0.5 cm in diameter. The sound attenuation achieved with three earmuffs, with and without venting, and a neoprene wetsuit hood currently used in the Diving Research and Diving Training Facilities at DRDC Toronto was assessed in both males and females. The observed average values in the audible frequency range (250 Hz to 8,000 Hz) were then applied to noise levels measured at twenty-two positions in the two facilities.

Averaged across venting and sound frequency, there was a small, albeit statistically significant difference in attenuation among the three earmuffs. Average values for the Peltor 10A, Viking and Moldex M2 were 31.4 dB, 29.2 dB and 32.6 dB, compared with 11 dB for the hood. As expected from both the manufacturers' specification and previous laboratory studies, the attenuation increased with frequency, peaking at either 4000 Hz or 6300 Hz. The highest observed attenuation for the Peltor 10A, Viking, and Moldex M2 earmuffs and the hood were 37.9 dB, 35.9 dB, 42.9 dB, and 26.7 dB, respectively. The difference due to gender was 2 dB, averaged across earmuffs, venting and frequency, never exceeding 5 dB either for the forty-eight combinations of earmuff, venting and frequency or for the hood at eight frequencies. Taken together, these results support the conclusion that, although gender was a significant factor, the effect on attenuation was relatively small.

The effect of venting the earmuffs was apparent for frequencies below 1000 Hz for all three earmuffs, ranging from a decrease in attenuation of 5 dB for the Moldex M2 to as much as 17 dB for the Peltor 10A and Viking muffs. The observed difference could not be explained by the size of the vent which was approximately the same across devices. An analysis of the attenuated noise levels in each of the hyperbaric facilities indicated that personnel might be at risk of acquiring a noise-induced hearing loss if they wore only the neoprene hood in the Dive Chamber of the DRF (500 Hz at POS 14, 15 and 16), if they wore only the hood in the Main Lock of the DTF (250 Hz to 2000 Hz at all positions) or if they wore any of the three vented earmuffs in the Main Lock of the DTF (250 Hz at all positions). Under these conditions, the attenuated levels ranged from 87.6 dB SPL (Moldex M2, vented, DTF, POS 19, 250 Hz) to 100.9 dB SPL (Hood, DTF, POS 21, 250 Hz). The corresponding dBA levels would be approximately 5 dB lower, i.e., 83 dBA to 95 dBA. Based on Treasury Board guidelines, personnel may be exposed to 87 dBA for 8 hours. For every 3 dB increment, the exposure duration should be halved. Thus, if the exposure level is 95 dBA, personnel should be exposed for no longer than 1 hour. This duration is well within the time it takes to introduce pressurized air into the chambers. Thus, it may be concluded that for the hood and muffs (unvented and vented) investigated, personnel should be adequately protected.

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List of abbreviations and acronyms

ADM (MAT)	Assistant Deputy Minister (Materiel)
ANSI	American National Standards Institute
CF	Canadian Forces
CFEME	Canadian Forces Environmental Medicine Establishment
dB	decibels
dBA	decibels, A-weighted to model the response of the human ear
dB SPL	decibels, sound pressure level
DOJ	Department of Justice
DRF	Diving Research Facility
DRDC Toronto	Defence Research & Development Canada – Toronto
DTF	Diving Training Facility
HL	hearing level; sound level required for threshold perception relative to normal hearing
Hz	Herz (cycles per second
ISO	International Organization for Standardization
STO/DEE	Support to Operations / Support to Development Engineering and Evaluation

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The risk of noise-induced hearing loss during simulated dives in Canadian Forces hyperbaric facilities

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This study was conducted in response to a Support to Operations/Support to Development Engineering and Evaluation (STO/DEE) request from ADM (Mat) for information relating to Canadian Forces divers' risk of developing noise-induced hearing loss during simulated dives. During a simulated dive, high pressure air is transferred into the dive chamber of a hyperbaric facility. The mechanism is audible and sufficiently high in level in adjacent areas to warrant the use of hearing protection. There were two parts to the experiment, the assessment of hearing protector attenuation and the measurement of sound levels. In Part I, hearing thresholds were measured at frequencies from 250-8000 Hz in twenty normal-hearing males and females (1) with the head uncovered and ears unoccluded, (2) while wearing a wetsuit hood, and (3) while fitted with three hearing protection earmuffs, unvented and vented. Venting, the practice of drilling a small hole in earcups, is meant to prevent eardrum barotrauma. Attenuation was derived by subtracting the unoccluded from the protected thresholds. In Part II, sound level measurements were made at twenty-two positions within the Diving Research and Diving Training Facilities of Defence Research and Development Canada – Toronto. Earmuff venting resulted in a decrease in attenuation of as much as 17 dB at 250 Hz and 500 Hz. Although it was determined that some of the protected sound levels might be unsafe, the exposure duration was sufficiently short to minimize the possibility of hearing damage.

La présente étude a été réalisée à la suite d'une demande de soutien aux opérations/au développement, à l'ingénierie et aux évaluations (STO/DEE) formulée par le SMA (Mat) relativement à la collecte de données sur le risque de perte auditive due au bruit chez les plongeurs des Forces canadiennes participant à des exercices de plongée expérimentale. Au cours d'une plongée expérimentale, de l'air haute pression est introduit dans la chambre de plongée d'une installation hyperbare par un procédé audible d'un niveau sonore justifiant le recours à une protection auditive dans les zones adjacentes. Divisée en deux volets, l'étude visait à évaluer le niveau d'atténuation sonore associé à certains protecteurs auditifs et à mesurer les niveaux sonores observés. Au cours du volet 1, les seuils d'audition ont été mesurés à des fréquences de 250-8 000 Hz chez 20 hommes et femmes normo-entendants, selon les paramètres suivants : 1) tête découverte et oreilles non occluses; 2) port d'une cagoule nautique isothermique; 3) port de trois modèles de serre-tête antibruit dotés ou non d'orifices de ventilation. Le perçage d'un petit orifice de ventilation dans les cache-oreilles vise à prévenir les barotraumatismes de l'oreille. L'atténuation sonore a été obtenue en soustrayant les seuils auditifs mesurés sans occlusion des seuils avec protection. Dans le cadre du volet 2, le niveau sonore ambiant a été mesuré à vingt-deux endroits dans les installations de recherche et d'entraînement en plongée de Recherche et développement pour la défense Canada – Toronto. Les orifices de ventilation ont entraîné une réduction du niveau d'atténuation sonore des protecteurs auditifs pouvant atteindre 17 dB à 250 Hz et à 500 Hz. Bien que certains niveaux sonores associés au port d'une protection auditive puissent poser un danger, la durée d'exposition était assez courte pour réduire au minimum le risque d'atteinte auditive.

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noise exposure; hyperbaric facilities, vented hearing protection attenuation

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